Chapter 1

Ground improvement techniques

Syllabus

Ground improvement techniques

- Advanced piling techniques - Stone Column, Vibro Floatation, Micro Piles, Soil Nailing
- Vertical drains-Sand Drains, Pre-Fabricated Vertical Drains
- Thermal Methods- soil heating and soil freezing.

GROUND IMPROVEMENT TECHNIQUES

- The ground can be improved by adapting certain ground improvement techniques. Vibro-compaction increases the density of the soil by using powerful depth vibrators. Vacuum consolidation is used for improving soft soils by using a vacuum pump.
- Preloading method is used to remove pore water over time. Heating is used to form a crystalline or glass product by electric current. Ground freezing converts pore water to ice to increase their combined strength and make them impervious. Vibro-replacement stone columns improve the bearing capacity of soil whereas Vibro displacement method displaces the soil. Electro osmosis makes water flow through fine grained soils.
- Electro kinetic stabilization is the application of electro osmosis. Reinforced soil steel is used for retaining structures, sloping walls, dams etc. seismic loading is suited for construction in seismically active regions. Mechanically stabilized earth structures create a reinforced soil mass.
- The geo methods like Geosynthetics, Geogrid etc. are discussed. Soil nailing increases the shear strength of the in-situ soil and restrains its displacement. Micro pile gives the structural support and used for repair/replacement of existing foundations.
- Grouting is injection of pumpable materials to increase its rigidity. The jet grouting is quite advanced in speed as well as techniques when compared with the general grouting.
- Rapid urban and industrial growth demands more land for further development. In order to meet this demand land reclamation and utilization of unsuitable and environmentally affected lands have been taken up. These, hitherto useless lands for construction have been converted to be useful ones by adopting one or more ground improvement techniques.

1.1 Advanced Piling Techniques

- Ground improvement techniques such as stabilization, vibro flotation, dynamic compaction, stone column, compaction pile and compaction grouting are given the maximum importance in present days to adapt weak soil into the proper stable ground for different civil engineering projects.

1.1.1 Stone Column

- Stone column ground improvement involves adding vertical columns of stone into the ground to a depth of at least 4m below the ground surface. A layer of compacted gravel can then be put over the top of the columns, ready for the construction of new house foundations. The stone column method is quick to construct and can be done at any time of the year.

- It is a ground improvement technique used to improve the load bearing capacity and reduce the settlement of the soil. It is also called as granular columns or granular piles. This technique is also known as vibro replacement.
- In this technique dense aggregate column (stone columns) is constructed by means of a crane-suspended downhole vibrator.
- Stone columns are constructed in soil to increase the load-bearing capacities of the native soil. The upper portion of the compacted granular column is provided with a rigid central core such that vertical loads imposed on the composite column are transferred to a deeper level on the compacted column where the column operates more efficiently.
- A probe is centrally penetrated downwardly into the compacted granular column, and the resulting cavity is filled with cementitious grout to form a solid core after hardening. The grout may be injected into the cavity so formed in the compacted column at the bottom of the probe as the probe is being withdrawn in predetermined quantities metered in synchronization with the rate of withdrawal of the probe from the core cavity.

Function

- Installation of stone column improves ground by reducing soil settlement. Due to its higher modulus of elasticity than that of soil, it absorbs more load than soil and reduces overall settlement.
- Since applied load distributes in between soil and stone column in the ratio of their stiffness, the load carrying capacity of soil also increases.
- Stone aggregates are used to fill stone column. Water can easily pass into the stone column. So, stone column helps in excess pore water pressure mitigation and accelerates the consolidation process.

Displacement method

- In this method, boring is done by displacing nearby soil. The soil is displaced laterally, due to which engineering property of soil gets change.
- Hole can be made by driving casing or tube into the ground. Best example of displacement method is vibro float method which is being used widely.
- It is done by two methods.
- Wet, Top feed method
- Dry, Bottom feed method

Non-displacement method

- In this method, boring is done without displacing nearby soil. Although there will be some displacement that can be neglected. Example – bored rammed method.

Advantages

- Reduce total and differential settlement.
- Increase the bearing capacity of strata to make it possible to use shallow foundation hence, saving money and time.
- Accelerates the rate of consolidation in cohesive soil by providing drainage to water.

1.1.2 Vibro Floatation

- Vibro flotation is a ground improvement technique used at a considerable depth that by using a powered electrically or hydraulically probe, it strengthens the soil.
- The vibro flotation will compact the soil making it suitable to support design loads. It involves the introduction of granular soil to form interlocking columns with surrounding soil.
- The technique is used to improve bearing capacity and reduce the possibility of differential settlements that might be allowed for the proposed loads.
- Sometimes it is also referred to as Vibro compaction and the ultimate concept is to repack soil particles by joining them together improving soil's bearing capacity. The compaction of soil can be obtained in soils as deep as 200 feet. The risk of liquefaction in an earthquake prone area is also drastically reduced.

Vibro flotataion Techniques

Vibro flotation can be obtained by using three different techniques:

- **Vibro Compaction method-** This method allows granular soils to be compacted. This method is only used to compact sandy soils.
- **Vibro Replacement method-** The technique is used to replace poor or inadequate soil material by flushing out the soil with air or water and replacing it with granular soil. This can be used in various soil types such as clay and sandy soils.
- **Vibro Displacement method-** This procedure is used with no or small amounts of water used during the technique. The probe is inserted into the soil and it will displace it laterally as the new soil column is being formed and compacted.

Vibro flotation Advantages

Vibro flotation is one affordable way to improve ground conditions when a deep layer of inadequate soil is found. The technique is so simple that will not require the delivery of additional materials or additional equipment other than the probe and the equipment that has it installed. The vibro flotation process can offer the following benefits:

- When the process is done properly, it will reduce the possibility of differential settlements that will improve the foundation condition of the proposed structure.
- It is the fastest and easiest way to improve soil when bottom layers of soil will not provide good load bearing capacity.
- It is a great technology to improve harbor bottoms
- On a cost-related standpoint, it helps improve thousands of cubic meters per day. It is faster than piling.
- It can be done around existing structures without damaging them.
- It does not harm the environment
- It improves the soil strata using its own characteristic
- No excavations are needed, reducing the hazards, contamination of soils and hauling material out from the site
- No need to manage table water issues, neither the permits required to manage water discharge and dewatering issues.
- The technique of vibro flotation can be adapted to each scenario and site
- When vibro flotation is performed at a site, it will reduce the possibility of liquefaction during an earthquake

1.1.3 Micro Piles

- Micropiles are small diameter piles (up to 300 mm), with the capability of sustaining high loads (compressive loads of over 5000 KN).The drilling equipment and methods allows micropiles to be drilled through virtually every ground conditions, natural and artificial, with minimal vibration, disturbances and noise, at any angle below horizontal. The equipment can be further adapted to operate in locations with low headroom and severely restricted access.
- The present invention relates to a method of joining a micro pile with an existing structure, and more particularly, to add a basic reinforcement according to occurrence of additional load due to settlement, flotation or extension of an existing structure, which is used for ground reinforcement in civil engineering and construction. The present invention relates to a method of combining micro piles with existing structures in the construction of micro piles that can be constructed in general.
- The construction method of the reinforcement micro pile according to the present invention includes:

  (a) drilling a hole for inserting a micro pile into the foundation concrete;

  (b) drilling holes for inserting micro piles into the foundation ground;

  (c) inserting the micro pile into the holes drilled in (a) and (b);

  (d) grouting or filling cement milk or mortar up to the foundation ground;

  (e) expanding a portion of the perforated hole in the base concrete in the circumferential direction;

  (f) fastening the load transfer member and filling the hole of the foundation concrete with cement milk or mortar.
- The size of the pile is determined by the load-bearing capacity of the ground and the size of rig that is able to access the piling location.
- Micropiles can also be used in combination with other ground modification techniques where complex site conditions and design specifications are present.
- In a typical installation process a high-strength steel casing is drilled down to the design depth. A reinforcing bar is inserted and high-strength cement grout pumped into the casing. The casing may extend along the full length of the pile, or it may only extend along part of the length of the pile, with the reinforcing bar extending along the full length.
- Drilling may be achieved by a removable bit, or by a sacrificial head to the steel casing.
- In some cases, the steel casing may be removed, or partially removed, and further grout pumped in at pressure.
- They can be installed in restricted access sites where there is low headroom by the use of lagging. This is where wood, steel or precast concrete panels are inserted behind the pile as the excavation proceeds so as to resist the load of the retained soil and transfer it to the pile. Greater capacity can be achieved by post-grouting within the bond length to increase frictional forces with surrounding soils.

There are advantages of micro piles include:

- They are small and relatively light.
- They are relatively inexpensive.
- They can be installed through almost any ground condition, making them suitable for

installation in environmentally-challenging conditions, such as for wind turbine towers.

- The limited vibration and noise causes little disturbance.
- Piling rigs can be low-emission or even electrically driven.
- They can be installed while avoiding existing utilities, meaning that expensive utility re-routing is not required.
- They can be installed close to existing walls with limited headroom and congested site conditions.
- They have a high load capacity and an ability to resist compressive, tensile and lateral loads.

Applications of Micropiles for Ground Improvement

- For Structural Support and stability
- Foundation for new structures
- Repair / Replacement of existing foundations
- Arresting / Prevention of movement
- Embankment, slope and landslide stabilization
- Soil strengthening and protection

1.1.4 Soil Nailing

- Soil nailing is a ground stabilization technique that can be used on either natural or excavated slopes. It involves drilling holes for steel bars to be inserted into a slope face which are then grouted in place. Mesh is attached to the bar ends to hold the slope face in position.
- They are commonly used as a remedial measure to stabilize embankments, levees, and so on. Other applications for soil nailing include:
  - Temporary excavation shoring.
  - Tunnel portals.
  - Roadway cuts.
  - Under bridge abutments.
  - Repair and reconstruction of existing retaining structures.
- The main considerations for deciding whether soil nailing will be appropriate include; the ground conditions, the suitability of other systems, such as ground anchors, geosynthetic materials, and so on and cost.
- Although soil nails are versatile and can be used for a variety of soil types and conditions, it is preferable that the soil should be capable of standing – without supports – to a height of 1-2 m for no less than 2 days when cut vertical or near-vertical.
- Soils which are particularly suited to soil nailing include clays, clayey silts, silty clays, sandy clays, glacial soils, sandy silts, sand, gravels. Soil nailing can be used on weathered rock as long as the weathering is even (i.e. without any weakness planes) throughout the rock.
- Soils which are not well-suited to soil nailing include those with a high groundwater table, cohesion-less soils, soft fine-grained soils, highly-corrosive soils, loess, loose granular soils, and ground exposed to repeated freeze-thaw action.

Design considerations that will inform the design include:

- Strength limit: The limit state at which potential failure or collapse occurs.

- Service limit: The limit state at which loss of service function occurs resulting from excessive wall deformation.
- Height and length.
- Vertical and horizontal spacing of the soil nails.
- Inclination of the soil nails.
- Ground properties.
- Nail length, diameter and maximum force.
- Drainage, frost penetration, external loads due to wind and hydrostatic forces.

Some of the advantages of using soil nailing include:

- They are good for confined spaces with restricted access.
- There is less environmental impact.
- They are relatively quick and easy to install.
- They use less materials and shoring.
- They are flexible enough to be used on new constructions, temporary structures or on remodelling processes.
- The height is not restricted.

Limitations of using soil nailing include:

- They are not suitable for areas with a high water table.
- In soils of low shear strength, very high soil nail density may be required.
- They are not suitable for permanent use in sensitive and expansive soils.
- Specialist contractors are required.
- Extensive 3D modelling may be required.

Applications of Soil Nailing Technique:

- Stabilization of railroad and highway cut slopes
- Excavation retaining structures in urban areas for high-rise building and underground facilities
- Tunnel portals in steep and unstable stratified slopes
- Construction and retrofitting of bridge abutments with complex boundaries involving wall support under piled foundations

1.2 Vertical Drains

- This technique involves the installation of artificial drainage paths or vertical drains into soft compressible soils.
- The prefabricated vertical drain (PVD) & Sand drain used by for specially designed to work effectively under high settlements.

1.2.1 Sand Drains

- Vertical sand drains are used as an effective technique for construction of structures, such as oil or gas storage tanks or airports, sea ports, harbor works or highway or railway embankments or dams, over highly compressible soils.
- The principle of sand drains is to provide additional vertical drainage faces in the form of cylindrical holes filled with clean sand.

- Structures constructed over highly compressible soils, soft marine clay deposits suffer very large consolidation settlements, which have the potential to cause serious damage or failure of such structures. Such soils, located in the coastal regions such as Mumbai, Calcutta, Visakhapatnam, and others, extend to large depths of up to 15 to 25 m or more.
- Pile foundations may not always be an effective solution for such conditions. The surface of such soil deposits is so soft that it is difficult to use heavy construction equipment for construction of structures over such soils. The progress of construction is often delayed or halted for several weeks, shooting up the project costs if conventional foundation techniques are used in such soils.
- Compacted embankments are usually constructed over such soils to provide a hard surface for construction and also to minimize the differential settlements.
- An ideal solution for this type of problems is to accelerate the rate of consolidation such that the potential settlements are completed before the construction of the structure.

Sand Drain is based on principles of rapidly and centrally dewatering day system.

- Sand Drain is a process of radial consolidation which increases rate of drainage in the embankment by driving casing into the embankment and making vertical boreholes.
- The holes are backfilled with suitable grade ofsand. Construction Process:
- Driven casing is withdrawn after sand has been filled.
- A sand blanket is placed over the top of sand drains to connect all sand drains.
- They accelerate the drainage; a surcharge load is placed on the sand blanket.
- The surcharge is in form of dumped soil.

Construction of Sand Drains:

- The sand drains installed below an embankment. A sand layer of 50-60 cm thickness is initially laid over the soft soil that not only serves as a drainage layer for the soft soil at top but also provides a working platform for construction of both sand drains as well as embankment. The sand layer also serves as a graded filter between the soft soil and the embankment and prevents loss of embankment material in to the soft soil.
- The embankment is built up to some height above the sand layer to facilitate partial consolidation of the soft soil. This facilitates the soft soil to gain some shear strength to support and sustain the sand drains. However, full height of the embankment is not constructed in single stage because the soft soil will not have sufficient shear strength to support the embankment, in which case the embankment would sink into the soft soil. After the embankment is constructed up to some height, the sand drains are installed.
- A circular casing or hollow steel mandrel, of about 25-cm internal diameter and 6-m height, is driven vertically into the soft soil up to the required depth through the embankment and sand layer. The soil in the mandrel is removed and the hole is back filled with clean sand. The mandrel is then removed. The embankment is then constructed up to the full height in stages. After allowing sufficient time for consolidation to complete, the required structure, such as pavement, airport, or oil storage tank, is constructed.

Advantages of Sand Drains:

The following are the advantages of using sand drains:

1. Provision of sand drains allows drainage of pore water in radial direction in addition to the drainage in vertical direction.

2. Since the permeability of soil in horizontal direction is usually several times larger than that in vertical direction, the rate of consolidation becomes considerably faster compared to conventional soil system.

3. With faster consolidation, the soil gains shear strength rapidly, allowing faster pace of construction and thus reducing the project cost.

4. The long-term stability of the structure is also increased significantly as the potential settlements are completed mostly before or during the construction.

5. Sand drains avoid potential problems during construction in soft compressible soils.

1.2.2 Pre-Fabricated Vertical Drains

- Prefabricated Vertical Drains (PVDs) are composed of a plastic core encased by a geotextile for the purpose of expediting consolidation of slow draining soils.
- They are typically coupled with surcharging to expedite preconstruction soil consolidation.
- Surcharging means to pre-load soft soils by applying a temporary load to the ground that exerts stress of usually equivalent or greater magnitude than the anticipated design stresses.
- The surcharge will increase pore water pressures initially, but with time the water will drain away and the soil voids will compress.
- These prefabricated wick drains are used to shorten pore water travel distance, reducing the preloading time.
- The intent is to accelerate primary settlement.
- Pore water will flow laterally to the nearest drain, as opposed to vertical flow to an underlying or overlying drainage layer.
- The drain flow is a result from the pressures generated in the pore water.

Advantages

- Decrease overall time required for completion of primary consolidation due to preloading
- Decrease the amount of surcharge required to achieve the desired amount of precompression in the given time
- Increase the rate of strength gain due to consolidation of soft soils when stability is of concern
- **Comparison to sand drains:** Economic competitiveness, fewer disturbances to the soil mass compared to displacement sand drains, and the speed and simplicity of installation. Also feasible to be installed in a non-vertical orientation.
- They have also outlined some technical advantages of PV drains compared to sand drains. They separate these advantages by sand drain type. There is displacement drains, which displace the soil as the drain is installed, and non-displacement, which does not displace the soil during drain installation.

They found the following advantages of PVDs:

Displacement

- considerably less disturbance of cohesive soils during installation due to: smaller physical displacement by mandrel and top, and typically static push rather than driving
- installation equipment usually lighter, more maneuverable on site
- do not require abundant source of water for jetting

Non-Displacement

- do not require control, processing and disposal of jetted spoil materials; fewer environmental control problems
- field control and inspection not as critical
- definite potential for cost economy
- eliminate cost of sand backfill of drains, quality control problems and related truck traffic
- control and inspection requirements are reduced due to simplification of installation procedures

General

- there is greater assurance of a permanent, continuous vertical drainage path; no discontinuities due to installation problems
- PVDs can withstand considerable lateral displacement or buckling under vertical or horizontal soil movement
- faster rate of installation possible
- where very rapid consolidation is required, it is practical to install PVDs at close spacing
- PVDs can be installed underwater and in a non-vertical orientation more conveniently

Disadvantages

- If the compression layer is overlain by dense fills or sands, very stiff clay or other obstructions, drain installation could require predrilling, jetting, and/or use of a vibratory hammer, or may not even be feasible
- Under such conditions, general pre-excavation can be performed if appropriate
- Where sensitive soils are present or where stability is of concern, disturbance of the soil due to drain installation may not be tolerable
- In such cases, sand drains installed by non-displacement methods or an alternate soil improvement technique may be more practical

1.3 Thermal Methods

1.3.1 Soil heating

- It has been observed that heating or cooling shows certain marked changes in the soil properties.
- Heating and cooling have been extensively used as soil improvement techniques. Whatever be the mode of thermal stabilization we opt for it has the following needs:

  -Thermal evaluation of heat flow

  -Heating or refrigeration system has to be designed

  -Strength and stress-strain -time properties of the soil have to undergo performance analysis

Concept of Heat Stabilization of Soil

- Like seepage or consolidation analysis of soil, a heat flow analysis can also be carried out. The transfer of heat in soil occurs by conduction, convection (free, forced, by thawing) and radiation.
- The most predominant mechanism of transfer is through conduction, which takes place in three constituents of soil which are soil solids, water (which may be in the form of a liquid, ice or moisture) and pore air.
- The phenomenon of heat conduction is influenced by soil thermal properties which are its

thermal conductivity, latent heat of fusion, the heat of moistureization of soil water and the heat capacity of the soil.

- The behavior of heat flow in soil is mainly governed by the latent heat of fusion of water on freezing and heat of moistureization of water on heating above 1000C. The latent heat of fusion can be defined as the heat amount that must be added to the unit mass of a substance to change it from liquid to solid or solid to liquid without any change in the temperature.
- It is noted that higher the heat input per mass of the soil (which should be treated), the greater would be the effect. A small increase in temperature will cause a strength increase in fine-grained soils due to the reduction of electric repulsion between the particles, pore water flow due to variation in thermal gradient and due to the reduction in moisture content because of increasing emoistureation rate.
- Therefore, it is found that it is technically feasible to stabilize fine-grained soils by heating. The following mentioned statement gives the temperature and the corresponding possible change in soil properties.

Applications of heat Stabilization of Soil

It is used in

- Landslide stabilization
- Improving soil undergoing collapsing
- Mat foundation construction
- Forming vitrified piles in place
- Reduction of lateral stresses acting ton retaining walls
- The method opted may be
- Combustion to electrical
- Investigations of microwave drying
- Soil fusion by laser beam

1.3.2 Soil Freezing

- Ground freezing is a soil stabilization technique carried out by continuously refrigerating the soil.
- There are numerous ways and technique of soil stabilization for deep excavation or tunneling. Some of them are grouting, heat treatment method and many more. One of the common and popular method used in the recent times is ground freezing technique.
- Ground freezing is a process of converting pore water or pores into ice by continuously refrigerating the soil.
- The water bearing soil is very losing and doesn’t have enough compressive strength and shear strength to withhold its own loads. To increase these strengths and make the water bearing strata temporarily impermeable ground freezing method is used.
- This is usually done to provide structural underpinning, temporary support and prevent ground water flow into the site area. When the water-bearing strata is frizzed, the water in it transforms into ice which becomes a seal against the water and strengthens the soil.
- In grouting, extraneous materials are used. But in this method no extra material is required and after the work is completed, the soil reverts into normal state as before.

- This method can be use in any type of soil, regardless of size, shape or depth of excavation, soil or rock formation regardless of structure, grain size or permeability. However, it is best suited for soft ground rather than rock conditions.
- It is applicable to a wide range of soils but it takes considerable time to establish a substantial ice wall and the freeze must be maintained by continued refrigeration as long as required.

Conditions Where Ground Freezing is Most Effective

- Ground where penetrability by drilling, jet grouting, clamshell excavation, or other vertical cut-off tools is limited.
- Filled ground and ground containing man-made obstructions.
- Virgin ground containing cobbles, boulders, or an irregular soil/rock interface.
- Ground that has been disturbed due to unstable conditions or water inflow.

Principles of Ground Freezing

- The major principle of this method is to convert the water into ice by external freezing methods to create a water seal and strengthen the soil. The effectiveness of freezing depends on the presence of water to create ice, cementing the particles and increasing the strength of the ground to the equivalent of soft or medium rock.
- If the soil has doesn't enough amount of water to fill all to pore when they freeze, then it may be necessary to provide extra water so that the pores are complete sealed. This method is very effective in the places where the ground is made up of silts. Other methods of grouting cannot be undertaken due to very fine pores.
- The strength achieved by the ground after installing this method depends on freeze temperature, moisture content and the nature of the soil. After the initial freezing has been completed and the frozen barrier is in place, the required refrigeration capacity is significantly reduced to maintain the frozen barrier.
- When the ground water is transformed into ice, the expansion takes place which is negligible, around 9% expansion is observed which doesn't impose any serious stress or strain on the soil.
- As this is an artificial method of refrigeration, a uniform freezing can be imposed on any type of soil which offers great security when compared to various grouting methods.
- As in all ground treatment techniques, adequate site investigation is necessary to allow the best system to be chosen and to design the appropriate array of freezing tubes and select plant of adequate power.
- Once the freezing process has begun, monitoring is required to ensure formation of the barrier wall and to verify when freezing is complete. During the drilling process, temperature-monitoring pipes are installed to measure the ground temperature.

Types of Ground Freezing Methods

- The types of ground freezing methods used for temporary support of a tunnel heading are discussed below:
    1. Indirect Method
    2. Direct Method

1. Indirect Method of Ground Freezing

- This type of freezing method is commonly used in every place for the stabilization of tunnel headings. In this method, a secondary coolant is circulated through tubes which are driven into the ground.

- The figure shows the schematic representation of indirect ground freezing method. Two coolants are used in this method. The first is the Ammonia and the second coolant is Calcium Chloride.
- The ammonia is compresses in the freezing unit and passes to cool down. The condenser cools down the ammonia from gasses form to liquid form. The water is cooled down in the cooling unit.
- This liquid ammonia is passed and the secondary coolant is cooled down by the liquid ammonia. The cooled brine solution is passed to the tubes driven parallel to the ground. This tubes freeze and the surrounding area of the ground is also freezes. This cycle is repeated till the required ground area freezes.
- The time required to freeze the ground will obviously depend on the capacity of the freezing plant in relation to the volume of ground to be frozen and on the spacing and size of freezing tubes and water content in the grounds.

2. Direct Method of Ground Freezing

This method is further divided into two types:

1. Direct, by circulation of the primary refrigerant fluid through the ground tubes

- In this type of direct ground freezing method, only Ammonia is used in the freezing process. The process is same as that of indirect method, but here only one coolant is used.
- The ammonia is compressed and passed into the tubes driven into the ground. This ammonia freezes the tubes which in turn freezes the surrounding ground. Time required for this process is same as that of indirect process, but the efficiency is higher when compared to indirect method.
- The choice will depend on plant availability, estimates of cost and perhaps personal preference.

2. Direct, by injection of a coolant into the ground, such as liquid nitrogen

- This method doesn’t require ant refrigeration plant. Ammonia is brought to the site under moderate pressure and stored at site in insulated tanks. Tubes are driven into the ground with the provision of return pipes to exhaust to atmosphere.
- There is an advantage for emergency use, i.e. quick freezing without elaborate fixed plant and equipment. This may be double advantageous on sites remote from power supplies. In such conditions the nitrogen can be discharged directly through tubes driven into the ground, and allowed to escape to atmosphere. Precautions for adequate ventilation must be observed.
- The speed of ground freezing with N2 is much quicker than with other methods, days rather than weeks, but liquid nitrogen is costly. The method is particularly appropriate for a short period of freezing up to about 3 weeks.
- It may be used in conjunction with the other processes with the same array of freezing tubes and network of insulated distribution pipes, in which liquid nitrogen is first used to establish the freeze quickly and is followed by ordinary refrigeration to maintain the condition while work is executed.
- This can be of help when a natural flow of ground water makes initial freezing difficult.

Advantages of Ground Freezing Technique

- Temporary underpinning of adjacent structure and support during permanent underpinning.

- Shaft sinking through water-bearing ground.
- Shaft construction totally within non-cohesive saturated ground.
- Tunneling through a full face of granular soil.
- Tunneling through mixed ground.
- Soil stabilization.

Disadvantages of Ground Freezing Technique:

- Very expensive.
- Needs continuously monitoring.
- Volume expansion of water during freezing, leading to soil heave and thaw settlement.